IN-SITU METROLOGY OF SWELLING EFFECTS ON CRITICAL DIMENSIONS IN LIGA PMMA MOLDS

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Sandia National Laboratories manufactures high precision microparts using LIGA technology. LIGA is the German acronym for x-ray lithography (Lithographie), electrodeposition (Galvanoformung) and molding (Abformung) [1]. Fabricating large batches of high aspect ratio metal microstructures has been demonstrated at Sandia and provides a unique opportunity to produce centimeter scale macroscopic parts with micrometer scale precision. [2, 3].

A challenge in LIGA processing is the fact that the favored x-ray lithography resist, polymethylmethacrylate (PMMA), swells approximately 0.4% in the aqueous electrolyte solution during electrodeposition [4]. The effect is significant in thick molds and for long electroplating times, and seriously impacts the fidelity of critical dimensions. Other geometric distortion occurs due to the bottom surface boundary condition of the PMMA; being fixed to the mold substrate [5, 6]. Auxiliary surrounding features which are put adjacent to features of critical dimension can limit the primary swelling [3, 6]. Complicated geometries pose a challenge for designing auxiliary features because the features must follow the perimeter of the part uniformly. Complex non uniform geometries of the auxiliary structures can lead to swelling effects that are difficult to predict.

In situ PMMA swelling measurements enable quick prototyping for the design of auxiliary structures to minimize the effects of swelling. When the PMMA mold can be measured in situ, as it swells, no time has to be spent electrodepositing metal into the mold and examining the final product. Some of the electrodeposited structures at Sandia may take several weeks to fully grow. In addition, with the presented methods, it is possible to monitor other time-dependent effects such as PMMA unwantedly delaminating from the mold substrate.

While final LIGA part metrology at Sandia is well understood [3, 7], methods to measure a submerged or wet PMMA mold had to be established. A View Engineering Voyager V6x12 programmable optical microscope is used for this metrology [8]. Experiments were conducted immersing the objective lens in a container of water, together with the PMMA, as well as keeping the objective lens above the water level. Both methods showed to be too sensitive towards movement of the water, which is unavoidable, because the stage of the microscope has to move to inspect all regions of the mold. We found that extracting the mold from the water solution under a 90 degree angle towards the water surface leaves water in the open areas of the mold without wetting the top edge of the mold, which is the edge of interest for the measurements to be conducted. Figure 1 shows the video capture of a structure edge in PMMA with the mold cavity filled with water. The image shows excellent contrast of the edge, making edge detection just as straight forward as it is in a dry mold. Illumination using high levels of coaxial light, versus colored LED ring light, produced the most suitable edge contrast.

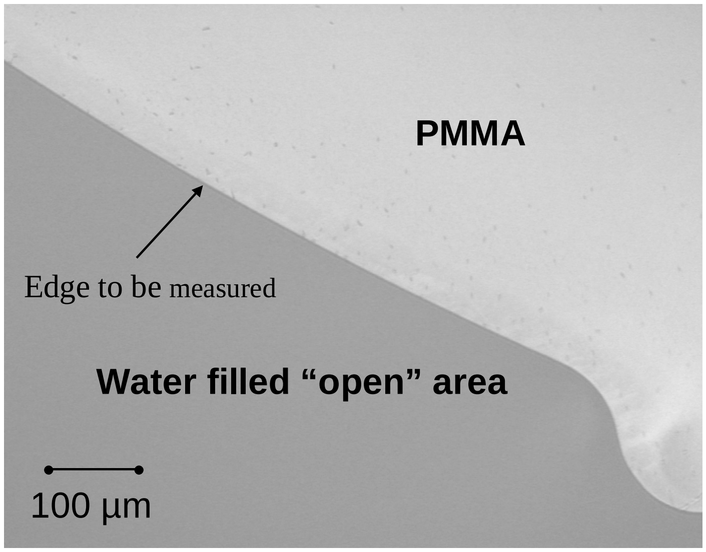

Figure 1: Typical microscope video image used for edge detection and measurement of the wet PMMA mold . The mold is taken out of the immersion bath and water remains in the mold without wetting the top edge that is inspected.

The top edge of a wet mold is examined in regular time intervals, thus following the swelling over the course of several days. Since the cavities of the mold are well saturated with water, drying of the mold during inspection is insignificant, especially because the mold generally is examined for less than one hour at a time.

Once the coordinate data is captured, the evolution of part geometries can be visualized against time. Even evolving coordinate point clouds can be compared to the part design (CAD). As an example, Figure 2 shows 143 µm line widths of a 1500 µm thick mold that are measured and show non-uniform narrowing from swelling over time.

Wafer bow from swelling PMMA resist can also be analyzed from the captured Z-axis coordinate data. Figure 3 shows a graph indicating total wafer bow evolving over time.

The demonstrated method to measure resist swelling in situ, is valuable for process control and quick prototyping. Future work will include the examination of simple mold structures to compare their swelling behavior with theoretical calculations.

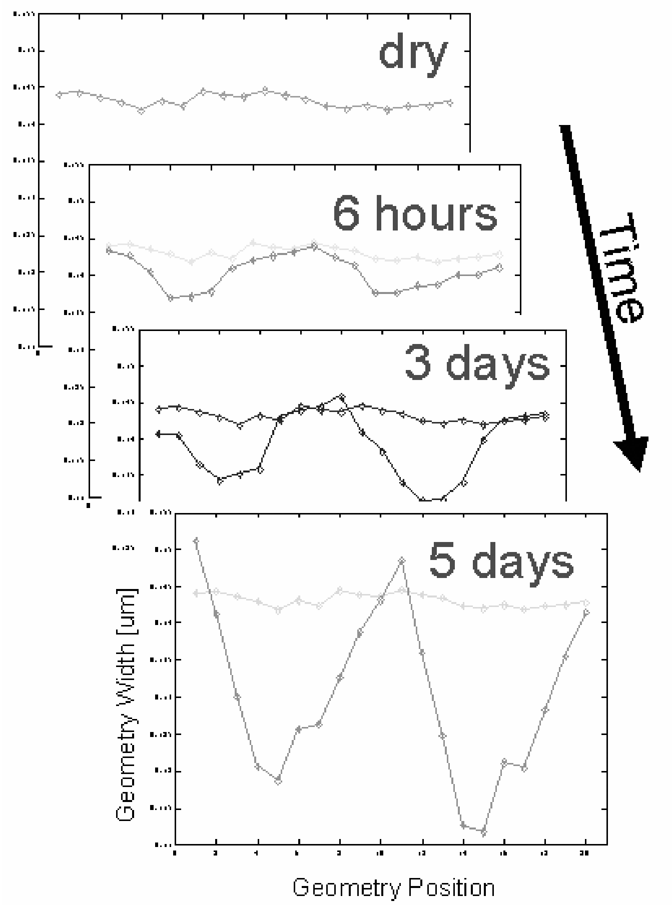

Figure 2: Line width measurements evolving over time from PMMA swelling. The dry data is presented in all graphs for reference. Between 3 and 5 days, resist delamination leads to large linewidth deviations.

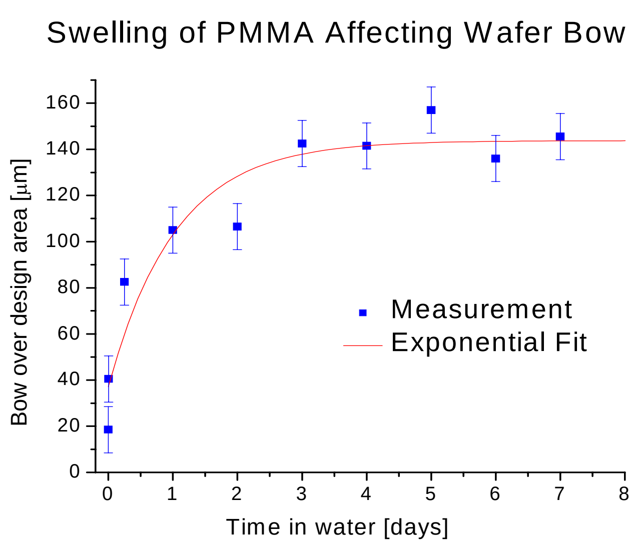

Figure 3: Total bow of the wafer (amplitude) from the thick PMMA resist swelling. An exponential saturation peaks after about 3 days.

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References:

1. Becker, E.W., et al., *Fabrication of microstructures with high aspect ratios and great structural heights by synchrotron radiation lithography, galvanoforming, and plastic moulding (LIGA process).* Microelectronic Engineering, 1986. **4**: p. 35-53.
2. Hruby, J., *LIGA Technologies and Applications.* MRS Bulletin, 2001. **26**(4): p. 337-340.
3. Aigeldinger, G., et al., *Final-Part Metrology for LIGA Springs, Build 1.* SAND REPORT, Sandia National Laboratories, 2004(2004-8153).
4. Goods, S.H., R.M. Watson, and M. Yi, *Thermal Expansion and Hydration Behavior of PMMA Molding Materials for LIGA Applications1.* SAND REPORT, Sandia National Laboratories, 2003(2003-8000).
5. Ruzzu, A. and B. Matthis, *Swelling of PMMA-structures in aqueous solutions and room temperature Ni-electroforming.* Microsystem Technologies, 2002. **8**(2-3): p. 116 - 119.
6. Griffiths, S.K., et al., *Dimensional errors in LIGA-produced metal structures due to thermal expansion and swelling of PMMA.* Journal of Micromechanics and Microengineering, 2004(14): p. 1548-1557.
7. Aigeldinger, G., J. Ceremuga, and D. Skala, *Large Batch Dimensional Metrology Demonstrated in the Example of a LIGA Fabricated Spring.* Book of Abstracts, HARMST 2003, USA. Microsystems Technology accepted., 2003: p. 263-264.
8. Ceremuga, J.T. and G. Aigeldinger, *Inspection Strategy for LIGA Microstructures Using a Programmable Optical Microscope.* SAND REPORT, Sandia National Laboratories, 2003(SAND2004-2289 / Submitted to Precision Engineering).